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Poster paper

Mechanical design of a dual-cryostat instrument for a high-field pulsed magnet

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The engineering of a dual-cryostat for a pulsed-magnet instrument at the Advanced Photon Source is presented. The dual-cryostat independently cools the magnet coil (using liquid-nitrogen) and the sample (using a closed-cycle refrigerator). Liquid-nitrogen cooling may allow a repetition rate of a few minutes for peak fields near 30 T. The system is unique in that the liquid-nitrogen cryostat incorporates a double-funnel vacuum tube passing through the solenoid's bore in order to preserve the entire angular range allowed by the magnet bore for scattering studies. Second, the use of a separate refrigerator for the sample allows precise positioning of samples in the bore while minimizing magnet vibrations propagating to the sample during pulsed-field generation.

1. Introduction

The dual-cryostat system for a high-field (30 T) single-solenoid pulsed magnet is designed to facilitate single-crystal X-ray diffraction techniques with magnetic fields applied in the scattering plane. The coil was designed, built and tested at the Institute for Materials Research (IMR, Tohoku University). As pulsed magnets are becoming more common at synchrotron X-ray facilities worldwide for studying materials in high magnetic fields (Mathon *et al.* 2007; Islam *et al.* 2009), we believe our instrument will open new opportunities for such studies.

2. Design requirements and specifications

In order to independently cool the solenoid and the sample, we developed a dual-cryostat (figure 1). A commercial closed-cycle refrigerator (1.4 K) was chosen to cool the sample, while for cooling the solenoid we have designed and built a liquid-nitrogen (LN2) cryostat. The use of a physically separate refrigerator for sample cooling allows precise positioning of the sample in the solenoid bore while minimizing magnet vibrations propagating to the sample during pulsed-field generation. The main requirements of the system were (i) the X-ray beam incident

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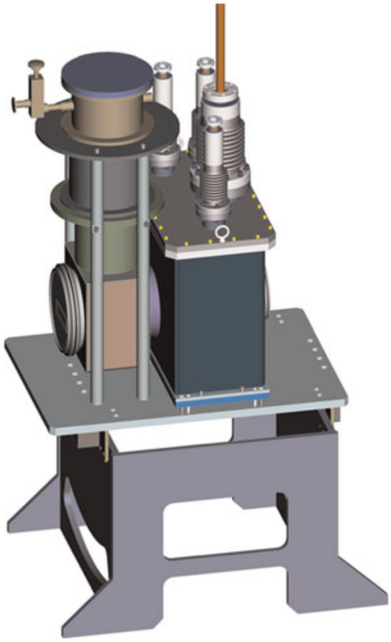

FIGURE 1. Dual-cryostat three-dimensional CAD model mounted on an existing support. The vacuum components and the pressure safety devices are not shown.

along the solenoid axis, (ii) sample mount at 90° with respect to the sample cryostat axis and (iii) preservation of the angular opening allowed by the solenoid. The sample cryostat (1) in figure 2 is rigidly connected to the LN2 cryostat (2) minimizing the distance between the sample cryostat vertical axis and the solenoid centre for a shorter heat path to the sample (3). A band clamp was used to connect the NW100 flanges between the cryostats. Attention has been paid to minimize the propagation of magnet vibrations to the sample during $\sim$4 ms pulsed duration.

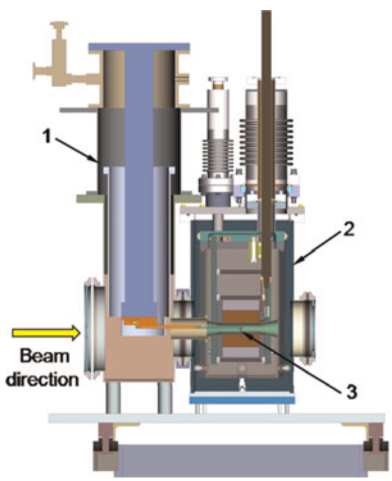

FIGURE 2. Vertical section along the X-ray beam axis. Overall dimensions: 552 mm × 413 mm × 704 mm (excluding the coaxial and the support).

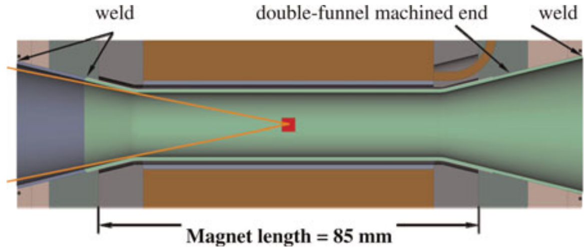

FIGURE 3. The double-funnel allows a maximum scattering angle of 23.6°.

However, if needed, a bellows segment could be added between the cryostats. For the current configuration (as shown in figure 1), the distance between the vertical axis of the sample cryostat (1) and the centre of the magnet coil is 180 mm. The cold finger consists of an Oxygen-Free High Conductivity (OFHC) Copper connector, an OFHC copper link and a sapphire plate. The copper connector is mounted to the cold probe, while the sample is mounted at the downstream end of the sapphire plate. For a very good thermal contact between the connecting parts, compressible indium foil is used with adequate pressure. An intermediate radiation shield around the cold finger can be attached to either the sample cryostat radiation shield (30 K) or the LN2 tank (77 K) in order to minimize the heat losses to the room temperature ambient. Radiation heating of the sample is about 43 mW for the 77 K option or about 2 mW for the 30 K option, respectively. The calculated temperature difference between the (4 K) cold probe and the downstream end of the sapphire finger was 1.4 K without a shield and 0.1 K with a 77 K shield. An interface thermal contact conductance coefficient of $0.01\ \mathrm{W\ mm^{-2}\ K^{-1}}$ was used for both copper-to-copper and copper-to-sapphire interfaces representing a poor contact. Also a conservative emissivity coefficient of 0.5 was used in the analyses. Therefore, a base temperature at or below 4 K should be achievable. To compensate for cryogenic temperature shrinkage, the cold finger was vertically offset 1.3 mm from the solenoid centre axis.

Finally, in order to preserve the entire range of scattering angle allowed by the solenoid, a tube with both ends flared named 'double-funnel' was designed in order to separate the LN2 and sample environments. The vacuum space inside the double-funnel is connected to the cryostat vacuum space (figure 3).

3. Tests and discussion

The initial plan was to flare one end of the 15.9 mm (0.625 in.) OD, 0.7 mm (0.028") thick 304 stainless-steel tube to a diameter of 31.4 mm, weld it to the LN2 vessel with the magnet in place and flare the other end *in situ*. We performed tests with a few 0.6 and 0.7 mm thick tubes and flared one end in order to reach the required diameter. All tube ends cracked at a diameter of about 21.4 mm, with thicker ones withstanding the process of flaring better. We decided to keep the wall thickness of 0.7 mm and to machine the larger end of the double-funnel to the required dimensions. The other end was flared *in situ* to 21.4 mm OD. Two to three layers of 0.1 mm thick Teflon tape have been wrapped around the double funnel for electrical isolation. Fixtures were used by the manufacturer (HiTech) in order to assure the concentricity and maintain 1 mm gap between the double-funnel and the magnet bore. The portion of the funnel that could not be obtained by flaring was machined and welded to the flared tube and afterwards to the LN2 vessel. Using a 0.7 mm thick stainless-steel tube is also the appropriate choice when welding thin parts to each other.

After assembly, the dual cryostat system was thoroughly tested for vacuum leaks. Each cryostat was tested separately, and the combined system was checked with and without air in the LN2 vessel to make sure they were ready for cooling. The tests for cooling the dual-cryostat system and field generation are underway at present. On-line tests with X-rays are planned for later this year.

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